A RANGE-WIDE ASSESSMENT OF THE CAPE THOMPSON MUSKOXEN POPULATION AND IMPLICATIONS FOR FUTURE DISTANCE SAMPLING SURVEYS

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INTRODUCTION

The Cape Thompson muskoxen population has been monitored since 1988 using minimum count methods. The traditional survey area focused on the coastal region (~0-30km from shore) from Cape Thompson in the north to the mouth of the Noatak River in the south (Fig. 1). This area was divided into 12 subunits which were surveyed intensively using fixed-wing aircraft, and most of the known population occurred in this area (Westing 2009). However since introduction, incidental sightings have increased in the surrounding area. In the last 20 years, the number of incidental sightings has increased dramatically, while in the last 5 years, counts within the traditional survey area have decreased (Westing 2009). For these reasons, it was deemed necessary to survey the known range and potential habitat in GMU's 26A and 23 north of Kotzebue that may be supporting muskoxen to try to understand the overall status of the population and develop a better tool for monitoring changes in population size and distribution. This increased the survey area from 10,440 km^2 to ~66,000 km^2, making a minimum count approach impractical.

In 2010, distance sampling methods were successfully used to estimate the size of the Seward Peninsula muskoxen population. We used this approach for the Cape Thompson survey as well, with the added benefit of increased efficiency for analysis. However, one requirement of this distance sampling methodology is that ~100 groups must be detected to achieve reasonably precise estimates, but only ~40 groups were typically detected in the historic survey area during minimum count surveys. For this reason, supplemental distance sampling surveys were also conducted over a portion of the Seward Peninsula with the goal of detecting ≥100 groups total. This would provide the number of detections necessary to estimate the detection function and provide reasonable levels of precision for abundance estimates. The joint estimation of this detection function does assume that the detection process is similar between the two areas, and bias could result if this assumption is not met. Terrain ruggedness and snow cover often differ between the two areas, possibly causing differences in detectability between the two regions. Future distance sampling surveys in the Cape Thompson area will allow us to examine these potential differences and are expected to reduce the reliance on observations from Seward Peninsula surveys. As a result, the collection of additional information specific to the Cape Thompson population may result in updated estimates over time as data are reanalyzed in light of new information.

To insure proper inference, there are several critical assumptions associated with distance sampling methods that must be met (Buckland et al. 2001):

1) All groups on the line are detected with certainty.
2) Groups are detected at their initial location.
3) Measurements are exact.
4) Detections are independent.

Because the area directly below the aircraft is obscured, the first assumption applies to the visible area nearest the plane. Teams were directed to pay particular attention to this region during surveys to ensure that no groups were missed at short distances. Muskoxen generally move little in response to aircraft and GPS marking error is minimal, so assumptions 2 and 3 are likely met under most circumstances. Detections of groups while off transect could introduce dependence between groups, violating the last assumption. Clear instructions to search upcoming terrain before leaving the transect to mark and count groups were used to reduce this potential problem.

METHODS

Surveys

Survey area boundaries were determined using locations of observed muskoxen and exclusionary habitat criteria (e.g. complete snow coverage with no exposed vegetation) for Game Management Units 23 and 26A. Areas at elevations over 700m (2300 feet) were considered non-habitat and were excluded from the survey. This criterion was set after analyzing the elevation of all muskoxen sightings in the muskoxen database that has been kept at ADFG since the muskoxen introduction. ArcGIS 10 was used with a Spatial Analyst extension to remove areas higher than 700 meters from a raster layer. The raster layer was converted to a coverage so polygons less than 1 square mile could be added back for continuity. Finally, the coverage was converted to a shapefile delineating survey boundaries. After removing areas of non-habitat, 65,833 km^2 were considered for the study. The supplemental survey areas on the Seward Peninsula were selected from GMUs 22E, and portions of 22D and 23SW within Bering Land Bridge National Preserve (BELA ,) covering 27,425 km^2 (Fig. 1,2).

Parallel transects were generated over the entire study region at two intensities depending on the suspected density of muskoxen in each area. Transects in most areas on the Seward Peninsula, the historic survey area for the Cape Thompson population, and a few smaller areas north of the Brooks Range and along the coast in unit 26A were placed at 6.4 km (4 mile) intervals. The remaining area was covered at 7.2 km (4.5 mile) intervals to reduce overall effort and cost in regions not likely to contain substantial numbers of muskoxen. This resulted in 79 transects being generated in the Seward Peninsula survey area and 205 transects in the entire Cape Thompson survey area (Fig. 1,2). All surveys were conducted at ~305m AGL using tandem fixed-wing aircraft (i.e. Supercub type aircraft) to reduce potential differences due to aircraft configuration and airspeed. During the 2010 Seward Peninsula survey, it was discovered that attempting to maintain a constant altitude in hilly terrain may decrease sightability in a wide strip near the line. To remedy this, we allowed flight altitudes AGL to decrease when transects crossed hills to minimize changes in flight angle. If a hill could not be passed over safely without increasing the flight angle, teams were instructed to stop surveying and gain altitude before the transect was continued. In continuous mountainous terrain an altitude that maintained ~305 m AGL over a majority of the transect was selected by the pilot, although this situation was relatively rare.

The pilot and observer worked together to search all terrain on both sides of the aircraft out to the midpoint between transects. When a group of muskoxen was detected, the team continued surveying until slightly past the group to prevent detections of additional groups after leaving the transect. The team then left the transect, marked the group location with a GPS, and recorded the total number of individuals and the number of short yearlings in the group. Digital photographs were used to confirm counts of larger groups when necessary. Teams were instructed to concentrate on the area nearest the aircraft first to ensure detection was 1.0 near the centerline.

Analysis

Perpendicular distances from the flight line to each observed group were calculated using ArcMap 9.3.1. The observed distance data were right truncated at 3.22 km, the distance at which adjacent transects overlapped. The left truncation distance, accounting for the unobserved strip beneath the aircraft, was determined by examining a histogram of the observed data. A sharp increase in the number of detections in subsequent distance categories was used to identify the width of the partially observable strip. Because survey altitude was allowed to decrease while passing over hills, a small number of groups were recorded within the left truncation distance and were discarded prior to analysis. Program Distance 6.0 (Thomas et al. 2009) was used to select the best fitting detection function, and AIC was used to select among competing models.

We re-fit the best approximating detection model in a Bayesian framework using R 2.12 (R Development Core Team 2010) and WinBUGS (Spiegelhalter et al. 2004). The overall model structure was similar to that used for the 2010 Seward Peninsula and contained 3 submodels: detection probability, probability of presence, and group size. However, two important improvements over the original 2010 analysis were made to the group size submodel based on the results of a similar analysis for Dall's sheep (Schmidt et al. *In press*). These additions included treating group size as a covariate influencing detection probability (see Buckland et al. 2004 and Marques et al. 2007) and the addition of a random effect. The former allowed detection probability to increase with group size, assuming that larger groups would be more detectable than smaller groups. The random effect helped to account for the overdispersed nature of the observed group sizes, reducing bias in abundance estimates. Without this random term, mean group size tends to be overestimated, inflating abundance estimates. Combined, these two additions are expected to produce more accurate and precise estimates than was previously possible.

We assumed that the Cape Thompson area would have a different probability of presence than the Seward Peninsula and that the probability of presence would be higher on longer transects (i.e. the number of muskoxen seen on longer transects will be higher than for shorter transects). We also included a random effect to account for remaining unexplained variation in presence on each transect. Cluster size was assumed to differ between the two survey areas, although detection probability was not. With this basic model structure, we generated estimates for subsections within the Cape Thompson and Seward Peninsula survey areas. To provide comparable abundance estimates between years for some survey areas on the Seward Peninsula, we also reanalyzed the 2010 data using this new model formulation. Abundances were estimated at the transect level, and estimates for each GMU or subunit were produced by weighting the abundance estimate for each individual transect by the proportion of that transect that was within the unit. The total transect-level abundance for the subunit was then converted to density before multiplying by the total area of the subunit to produce the overall abundance estimate.

RESULTS

All surveys were conducted March 03 to April 01 to provide similar weather and lighting conditions. Snow coverage was adequate (complete or near complete) in each survey area. Many areas that usually remain snow free had abnormally extensive snow cover due to higher than average snow fall and icing events that may have prevented snow from blowing away.

We determined that 200 m was an appropriate left truncation distance to account for the area with limited visibility under the aircraft, and the number of detections increased dramatically at distances >200 m from the transect line. We also right truncated the data at 3.2 km, the distance between the closest transects. After right and left truncation, 85 detections from the Seward Peninsula survey and 39 from the Cape Thompson survey remained for analysis. This was in line with our original goal of ≥100 total groups. Both the hazard-rate and half-normal detection functions fit the data, but the half-normal was selected based on AIC (ΔAIC = 1.0). The detection function for the 2011 surveys indicated that detection probability was very near 1.0 at 500 m, suggesting little to no bias in the 2010 estimates due to the larger left truncation distance in that year (Fig. 3). The Bayesian estimates for each subunit had CV's

<15% for the 2011 survey (Table 1), and the updated estimates for 2010 were lower and more precise than the previous iteration due to the updated group size submodel (Table 2). Based on this analysis, we estimated there were 447-612 (95%CI) in the entire northern survey area in 2011. Estimates were also generated for the traditional core sample area (176-248 95% CI), Unit 26A (187-279 90% CI) and the Cape Thompson population that exists in Unit 23 (244-355 95% CI) (Table 1, Fig. 4). Please refer to the discussion section for more information about subdivided estimates and their limitations. All of these data are presented as ranges rather than point estimates due to the fact that the estimates may change in future years as more area specific data are available. For the Cape Thompson survey area 49% of observed muskoxen were in the traditional Cape Thompson survey area, 42% were found in 26A, and the remaining 9% were found in other areas of Unit 23. There was a dramatic group size difference between areas that may influence the accuracy of estimates (26A mean 14 SD 15.5 vs traditional area mean 7 SD 5.7) (Fig. 5). We also estimated 354-473 (95%CI) muskoxen in BELA (portions of Unit 22E and Unit 22D) on the Seward Peninsula. During the 2011 survey, group detections from 22D were used to help estimate detection probability for 22E and the Cape Thompson Population, but we did not estimate abundance in this area due to sampling limitations (see Discussion). The 2011 partial survey of the Seward Peninsula was specifically conducted to locate additional groups to augment the detection function for the Cape Thompson muskoxen survey. It was not designed to estimate changes in 22D, 22E or the Seward Peninsula population. However, there was some limited evidence that portions of the Seward Peninsula population may have declined between 2010 and 2011 (Tables 1 and 2), although due to animal movement and distribution, strong conclusions cannot be reached until a complete survey is performed.

DISCUSSION

Our results confirm previous work suggesting that distance sampling is a useful tool for estimating muskoxen abundance at a population wide level (Schmidt et al. 2010). We were able to successfully produce estimates for the Cape Thompson population by combining information from the Seward Peninsula to help estimate the detection function. There would not have been a sufficient number of detections in the Cape Thompson area alone for this method to be successful, although future surveys will decrease the reliance on detections from other areas. Improvements to the group size submodel used here also increased precision and accuracy and should improve the ability to detect population trends. The survey protocol, including the modifications made to both the field and analytical methods, should be directly applicable to the 2012 Seward Peninsula survey and future Cape Thompson surveys with little modification.

While we were able to precisely estimate the size of the Cape Thompson population, it is important to consider the assumption that the detection process is similar between the two main survey areas. Because a majority of the detection information came from groups observed on the Seward Peninsula, abundance estimates for the traditional Cape Thompson survey area could be biased low if true detection probabilities are lower in that area for some reason (e.g., incomplete snow cover, more rugged terrain). The opposite bias may apply to the Seward Peninsula estimates, although to a lesser degree due to the fewer number of detections in the Cape Thompson area. Because of the strong dependence on the Seward Peninsula survey, the estimates for the Cape Thompson survey area should be considered provisional until additional surveys are completed. At this stage, it is inappropriate to use these data to interpret population trends or trajectories. After sufficient data have been collected from each area of interest, we will begin to be able to assess population status. We did not present point estimates specifically to discourage the interpretation of increases or decreases when comparing historic minimum count data with a distance sampling estimate that may be updated in the future. It is important to consider potential variability due to small scale movements that may lead to the inclusion or exclusion of groups from year to year. For example, for the last few years, a group of >30 muskoxen has been present around Cape Sabine. It is most likely that in previous years, this group occurred within the traditional core.

Estimates for the traditional survey area should be interpreted with care due to sampling limitations. The fewer group observations in an area, the more reliant the model is on information from other areas and the more likely an estimate may be biased. This is not accounted for in the credible intervals because of the assumption that using detection information from another area is appropriate. As additional data are collected, estimates for this area will become less reliant on data from other areas, and we will be able to assess the validity of this assumption directly. We will also be able to directly test for differences in detection between survey areas and adjust estimates accordingly. If future work finds little difference in detection between the two areas, then all data can be combined to improve estimates for both populations and point estimates will be generated for trend analysis.

Differences in the 2010 vs. 2011 estimates for the subunits on the Seward Peninsula should be interpreted carefully because the 2011 survey was not specifically designed for abundance estimation throughout this area. The purpose of the surveys on the Seward Peninsula was primarily to gain detection information to support the Cape Thompson survey, although a few areas were adequately covered (i.e. 22E and BELA). Because some transects crossed the boundaries of individual hunt units, estimates were weighted by the proportion of each transect that occurred in each subunit (Schmidt et al. 2010). This overlap was much more extensive in 2010 than in 2011 and could account for some of the changes between years if fewer adjacent groups were used to calculated estimates for a subunit. Also, muskoxen are often found on the borders between subunits and small movements into other subunits can affect local estimates, particularly if groups are large. In 2011, this could have influenced estimates for all subunits in 22D because the adjacent units (22C, 22B West) were not surveyed. Also, some areas known to contain muskoxen were not included in the survey (e.g. Port Clarence in 22D SW). Because coverage was incomplete and adjacent units were not surveyed, we found it inappropriate to estimate abundance for units in 22D for 2011. We consider it necessary to complete the 2012 Seward Peninsula muskoxen survey before appropriate conclusions about the status of the 22D and 22E subunits can be made.

Our modifications to the 2011 field protocol also appeared to correct some of the problems we observed during the 2010 survey, primarily the large (500 m) left truncation distance. Relaxing the requirement to maintain a constant AGL in hilly terrain appeared to increase visibility and detection probability near the aircraft, reducing the width of the partially observed strip by >50%. We were also able to assess the assumption of 100% detection at 500 m by calculating the detection probability at this distance in 2011. We found it to be ~1.0, suggesting that a truncation distance ≤500 m would not induce much bias. However, this would decrease survey efficiency due to an increased number of observations that would be excluded from analysis. Detection probability and precision were high with a transect spacing of up to 7.2 km (4.5 miles), indicating that a transect spacing of <6.4 km (4 miles) is not necessary for future surveys.

CONCLUSIONS/RECOMMENDATIONS

Based on the results from this work, we have a few ideas and suggestions for improvements to future distance sampling surveys for muskoxen. Optimal transect orientation, length, and border overlap have not been formally discussed and could help to reduce the potential for annual fluctuations in estimates. Because movement between adjacent units can cause fluctuations in estimates, it may be useful to discuss how best to address this issue. Analysis could also be more efficient if transects were generated based on the subunits for which estimates are desired. Using the proportion of each transect that occurs in each unit is an ad hoc solution that could introduce some variation into the annual estimates.

We found detection probability to be quite high across the entire visible strip, suggesting that transect spacing can remain ≥4 miles while producing useful estimates for all subunits. Transect spacing could probably be increased to 5 miles without much loss of precision, if cost reduction was a significant factor. Conversely, transect spacing of <4 miles may have little positive impact on precision but will increase survey cost. Other possibilities for reducing effort might include reduced transect densities in some areas, depending on management objectives. For units where precise estimates are important for hunt management and particularly those with small populations, additional transects may be flown by different teams to increase sample sizes. We also recommend that future surveys be conducted exclusively from tandem aircraft to reduce differences in detection probability caused by aircraft type. Although we have not been able to test the magnitude of this potential problem, it is likely that differences in airspeed and configuration could introduce variability.

Finally, it is worth considering whether there are any relevant covariates to include in the model for the detection function. For example, it might be useful to include terrain ruggedness or snow conditions as factors to help explain local variation in detection probability. This would help produce more accurate estimates at the subunit level and could help reduce annual fluctuation due to changing covariate values. In reference to terrain ruggedness, 26A may be more similar to the Seward Peninsula and may have less problems with comparability than the portions of Cape Thompson population that occur within Unit 23. Snow information should be collected on a transect level and included as a covariate in future surveys since data from multiple years may be combined and snow is known to have a significant impact on sightability.

LITERATURE CITED

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, USA.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas, Eds. 2004. Advanced distance sampling. Oxford University Press, Oxford, United Kingdom.

Marques, T.A., L. Thomas, S.G. Fancy, and S.T. Buckland. 2007. Improving estimates of bird density using multiple-covariate distance sampling. Auk 124:1229-1243.

R Development Core Team. 2010. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org. Accessed May 17, 2011.

Schmidt, J.H., T.S. Gorn, and C. Westing. 2010. Using distance sampling to estimate muskoxen abundance on the Seward Peninsula, Alaska. Unpublished report. 16p.

Schmidt, J.H., K.L. Rattenbury, J.P. Lawler, and M.C. MacCluskie. *In press.* Using distance sampling and hierarchical models to improve estimates of Dall's sheep abundance. Journal of Wildlife Management XX:XX-XX.

Spiegelhalter, D. J., A.Thomas, N. G. Best, and D. Lunn. 2004. WinBUGS Version 1.4.1. User manual. MRC (Medical Research Council) Biostatistics Unit, Cambridge, United Kingdom.

Thomas, L., J. L. Laake, E. Rexstad, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. L. Borchers, D. R. Anderson, K. P. Burnham, M. L. Burt, S. L. Hedley, J. H. Pollard, J. R. B. Bishop, and T. A. Marques. 2009. Distance 6.0. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. <http://www.ruwpa.st-and.ac.uk/distance/>

Westing, C. 2009. Unit 23 muskox. Pages 34-47 *in* P. Harper, editor. Muskox management report of survey and inventory activities 1 July 2006-30 June 2008. Alaska Department of Fish and Game. Project 16.0. Juneau, Alaska, USA.

Figure 1. Locations of transects completed during the 2011 Cape Thompson muskoxen survey.

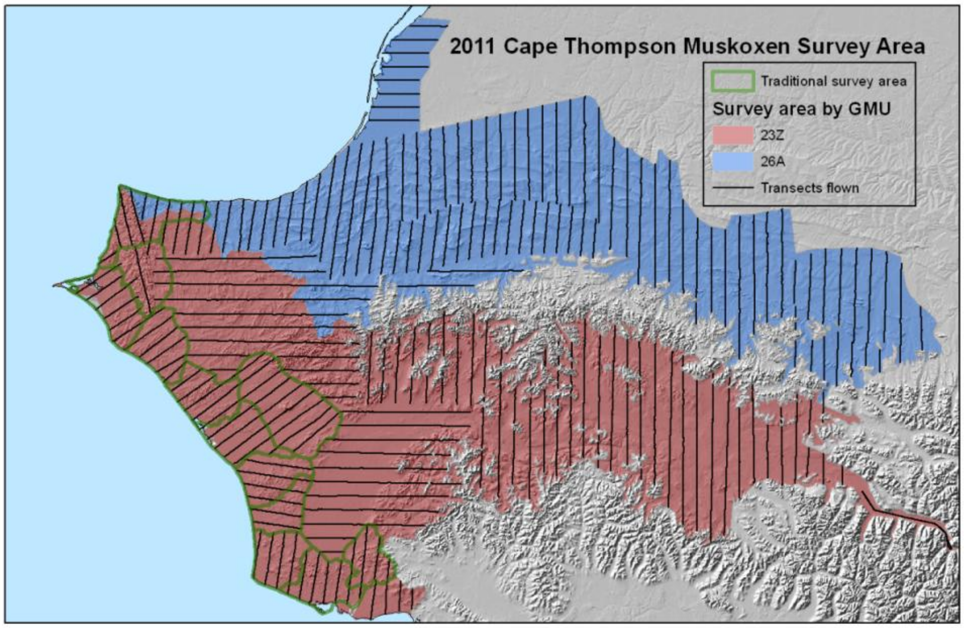


Figure 2. Locations of transects completed on the Seward Peninsula in support of the 2011 Cape Thompson muskoxen survey. The green shade indicates the border of Bering Land Bridge National Preserve (BELA).

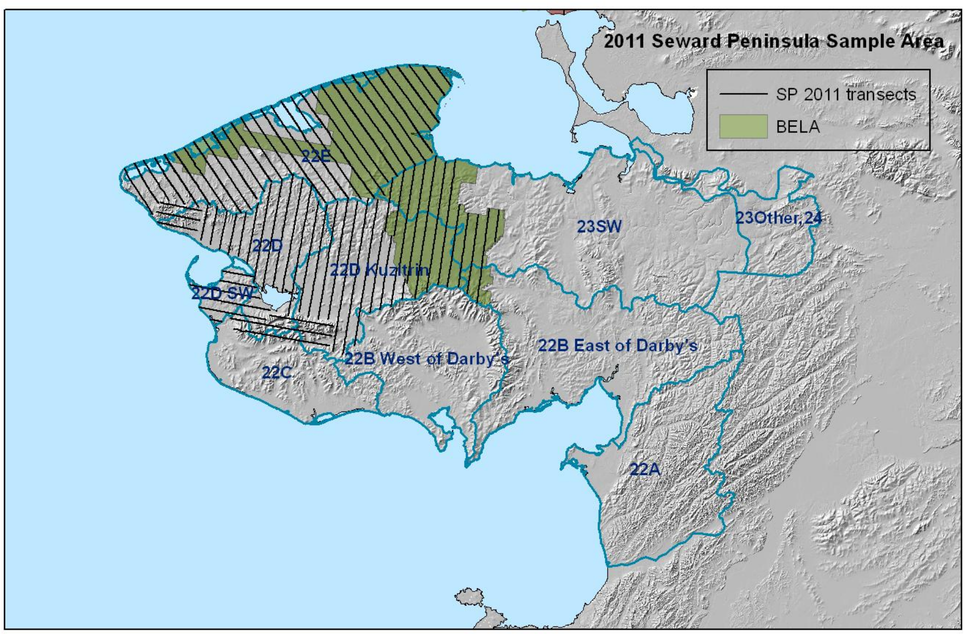


Figure 3. Histogram of the data from the Cape Thompson and Seward Peninsula survey areas combined after left and right truncation. The solid line represents the fitted half-normal detection function for a basic model assuming a linear decline in detection probability with distance. The bars indicate the relative number of observations in each distance category.

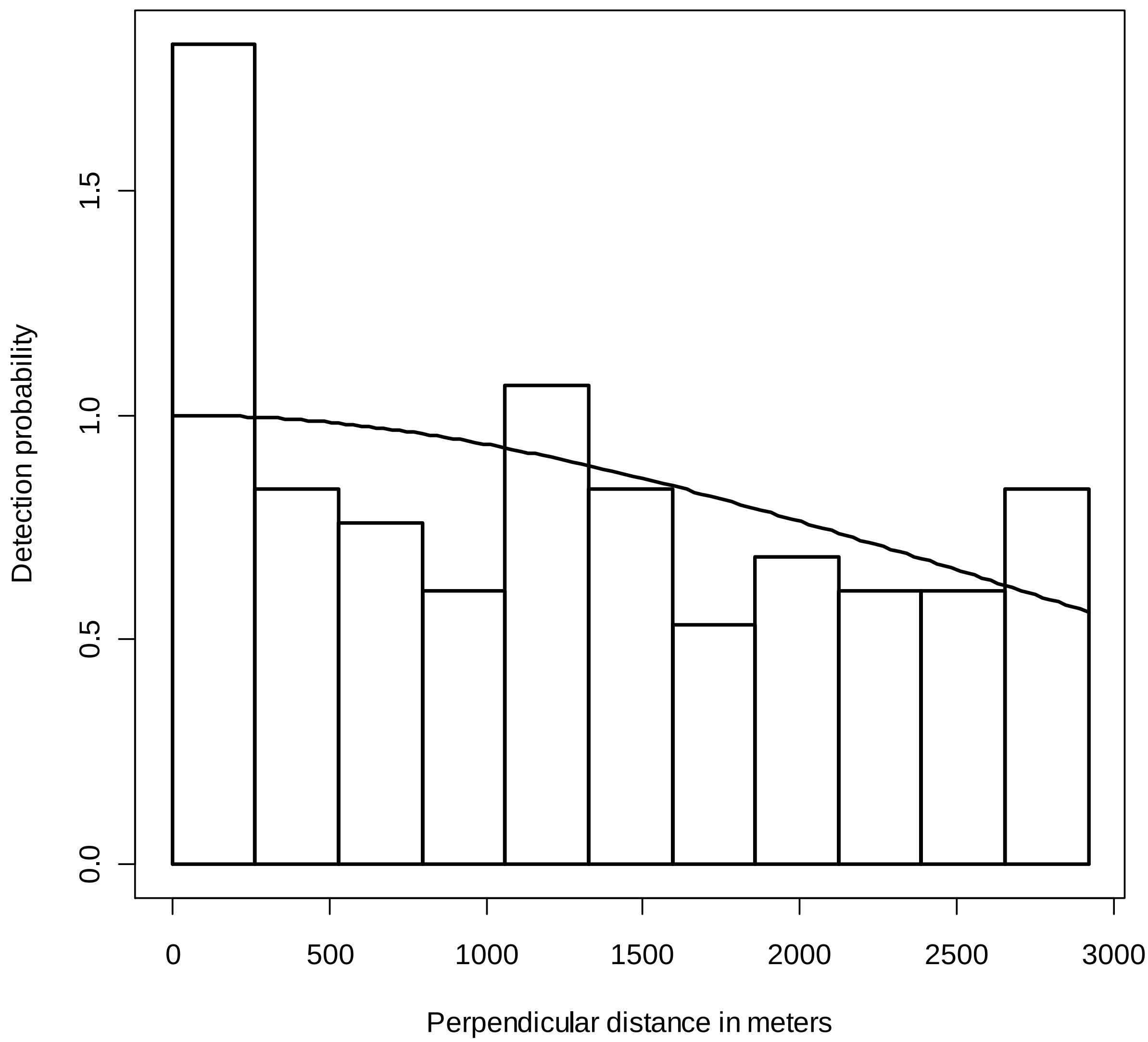


Figure 4. Histogram comparing minimum counts through time and the 2011 estimate based on distance sampling.

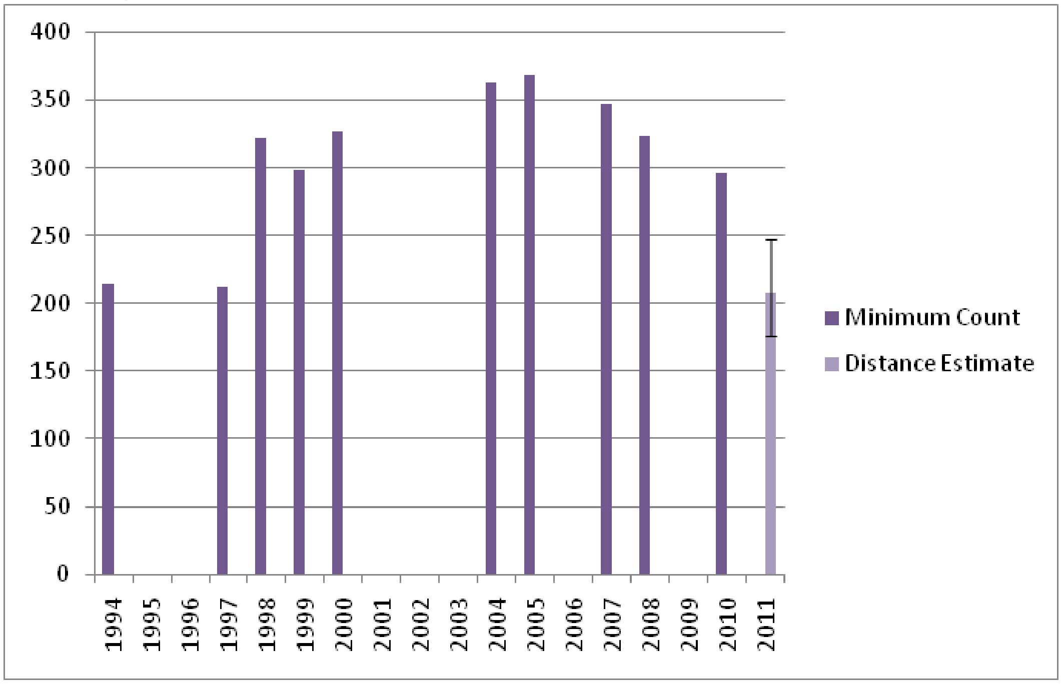
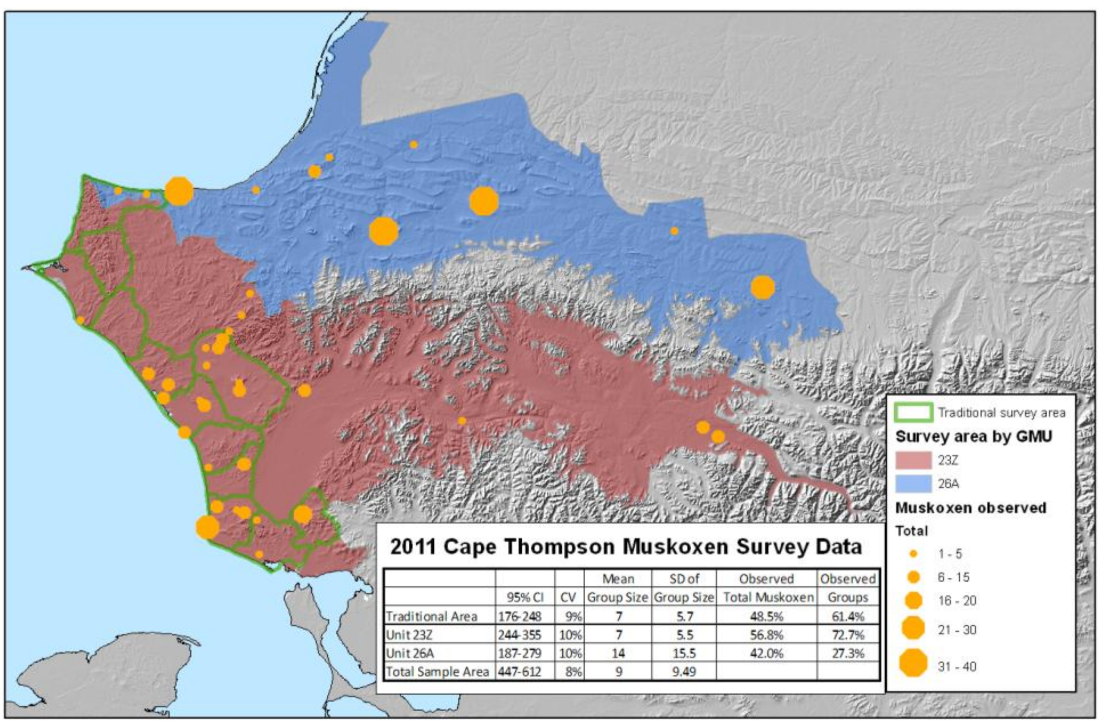


Figure 5. Locations and relative sizes of each group detected in the Cape Thompson survey area.



	95% CI	CV	Mean Group Size	SD of Group Size	Observed Total Muskoxen	Observed Groups
Traditional Area	176-248	9%	7	5.7	48.5%	61.4%
Unit 23Z	244-355	10%	7	5.5	56.8%	72.7%
Unit 26A	187-279	10%	14	15.5	42.0%	27.3%
Total Sample Area	447-612	8%	9	9.49		

Table 1. 2011 muskoxen abundance estimates with 95% credible intervals and coefficients of variation (CV) for the traditional Cape Thompson survey area, the entire northern survey area within GMU 23 and 26A, each GMU subunit, and Bering Land Bridge National Preserve.

Subunit	Mean	CV	2.5%	97.5%
Northern Area				
CAKR Traditional	208	9%	176	248
23	290	10%	244	355
26A	226	10%	187	279
Northern Total	515	8%	447	612
Seward Peninsula				
22E	693	6%	627	789
BELA	401	8%	354	473

Table 2. Updated 2010 muskoxen abundance estimates with 95% credible intervals and coefficients of variation (CV) for each GMU subunit on the Seward Peninsula.

Subunit	Mean	CV	2.5%	97.5%
22A	86	20%	62	128
22B East	56	34%	33	106
22B West	364	8%	320	430
22C	402	7%	357	464
22D Remainder	481	6%	433	546
22D Kuzitrin	237	8%	207	285
22D SW	160	9%	135	191
22E	879	5%	801	992
23 SW	175	15%	137	241
23 Out, 24	120	14%	93	159
Total Population	2903	5%	2690	3271
Western Portion	2616	5%	2436	2924
Eastern Portion	271	14%	216	360